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ZTFJ070412.91-112403.2: A KH 15D-like object with additional variability?

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Abstract: ZTFJ070412.91-112403.2 exhibits characteristics and variability reminiscent of a KH 15D binary system accompanied by a circumbinary disk. The corresponding ephemeris for this system is Min I = 2458238.8(5) + E* 34.57(2). However, there appears to be additional variability beyond what is typical for a KH 15D object, potentially attributable to surrounding dust clouds.

1 Introduction

Objects akin to Kearns-Herbst 15D (KH 15D) represent a distinctive and infrequent class of young binary systems enveloped by inclined circumbinary disks [1]. These systems manifest periodic episodes of dimming and brightening with durations of tens of days, characterized by exceptional sharpness and depth. This behavior is conjectured to arise from a circumbinary disk intermittently eclipsing one or both binary stars along our line of sight. Moreover, long-term variations in the light curve over extended periods furnish insights into disk precession and the stellar masses and orbital dynamics within the binary system [2].

An illustration based on the prototype KH 15D is shown in Fig. 1. The "advancing screen", as represented by the gray screen, moves across the binary orbit of Star B (blue circle) and Star A (red circle) in the direction of the arrows. While no eclipses occur in the graph on the top left, in the graph on the top right, the blue star is permanently eclipsed, while the red shows regular eclipses. On the bottom right, the blue star shows regular eclipses, while on the bottom right, both stars are permanently eclipsed. This leads to the mentioned long-term brightness fluctuations over decades and centuries.

KH 15D entities merit special attention due to their portrayal of a transient stage in binary star system evolution, affording a glimpse into intricate star-disk interactions. Their investigation holds promise for advancing our comprehension of early stellar evolution and the prerequisites for planetary genesis.

Motivated by this, one of the authors (Klaus Bernhard) conducted a survey aimed at identifying analogous systems within ongoing all-sky variability surveys, particularly focusing on the variable star catalog compiled from the Zwicky Transient Facility.

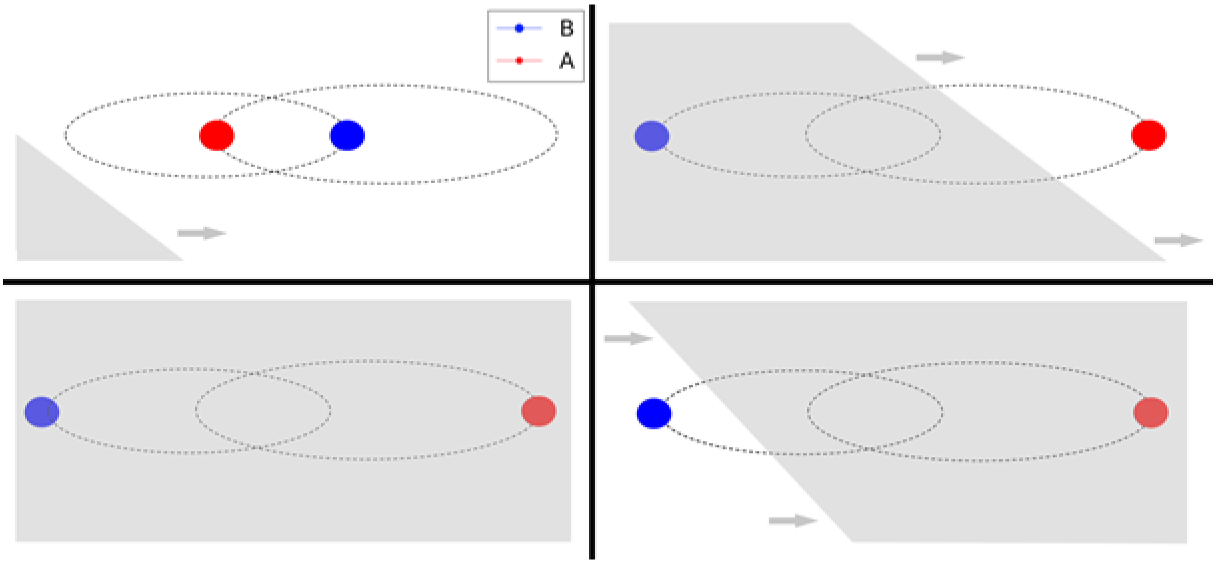

Figure 1: Illustration of a circumbinary ring moving across a KH 15D object.
Credit, Aylin Garcia Soto (Creative Commons, CC BY-SA 4.0)

2 Observation and data analysis

The exploration commenced with an examination of two ZTF catalogs of variable stars, comprising approximately 780,000 periodic variables with classifications and an additional 1,000,000 suspected variables lacking classifications. These catalogs rely on data obtained from the Zwicky Transient Facility (ZTF), a time-domain survey operational since 2017 at Palomar Observatory. The ZTF camera employs e2v CCD231-C6 devices and is affixed to the Palomar 48-inch Samuel Oschin Schmidt Telescope. Scanning at a rate of 3750 square degrees per hour across three passbands (g, r, and partially i), it achieves a limiting magnitude of 20.5 mag, rendering ZTF data highly suitable for variable-star investigations [3], [4], [5], [6].

In pursuit of objects akin to KH 15D, eclipsing entities with periods exceeding 10 days and amplitudes of at least approximately 1.5 mag were methodically scrutinized within both ZTF catalogs. This search yielded three promising candidates: ZTF J202055.22+381323.1, ZTF J071445.39-090152.1 and ZTF J070412.91-112403.2. The first two (ZTF J202055.22+381323.1 and ZTF J071445.39-090152.1) were previously documented in a 2022 international collaboration led by W. Zhu [7] and were called “Bernhard 1” and “Bernhard 2”. That publication provides further insights into the search program. The third candidate, ZTFJ070412.91-112403.2, was not thoroughly examined previously due to significant scatter. However, given its unique characteristics, it underwent detailed scrutiny, forming the core focus of this study.

ZTFJ070412.91-112403.2 is catalogued with the primary designation GDS_J0704129-112403 (17.34 mag, range 2.57 mag, r band) in The International Variable Star Index of the AAVSO [8].
Data sourced from the Gaia DR3 catalog [9] provide the following information:
- Right Ascension (RA): 07h 04m 12.921s (J2000)
- Declination (DEC): -11° 24' 03.224" (J2000)
- G magnitude: 17.88
- Distance: 1607.99 pc (1340.93-1917.19, rmedphotogeo, [16])

Taking into account these data and an interstellar absorption AV of 2.4 mag [17], an absolute magnitude in the Gaia G band of about 5.0 can be estimated. This suggests that ZTFJ070412.91-112403.2 is not a giant star but aligns with results obtained from the ML tool for open cluster membership [10], indicating its probable classification as a young stellar object (YSO). For comprehensive investigation, data from the NASA TESS mission and our own observations (Wolfgang Moschner, Chilescope) were additionally incorporated.

NASA TESS Mission: Launched in 2018, the Transiting Exoplanet Survey Satellite (TESS) mission aims primarily at discovering transiting exoplanets via high-precision time-series photometry. TESS's four identical cameras collectively cover a field of view spanning 24° × 96° and observe a given sky region for 27.4 days (one observing sector). TESS records red optical light within a broad wavelength range of approximately 600−1000 nm, centered on the traditional Cousins I band. Data processing involved the utilization of TESScut and Lightkurve programs [11], [12], [13]. It is important to note that due to dense star fields and the large pixel size of TESS, precise pixel-level data evaluation and consideration of neighbouring pixel brightness were imperative.

Chilescope: Additional Observations
In 2024, one of the authors (Wolfgang Moschner) conducted supplementary observations using a rented telescope at Chilescope Observatory in Chile. These observations captured two time series, each spanning several hours, focused on the phase position of maximum light.
Observational Details:
- Telescope: 500 mm ASA Astrograph f/3.8 (focal length = 1900 mm)
- Camera: FLI Proline 16803 CCD Camera
- Filter: I-U
- Exposure Time: 300 seconds
- Location: Chilescope/El Sauce Observatory, Chile (http://www.chilescope.com/)

3 Results

An analysis of ZTF data utilizing the Anova method of Peranso [14] yielded the subsequent ephemeris:

Min I (HJD UTC) = 2458238.8(5) + E* 34.57(2) (I)

The phased light curve is shown in Figure 2.

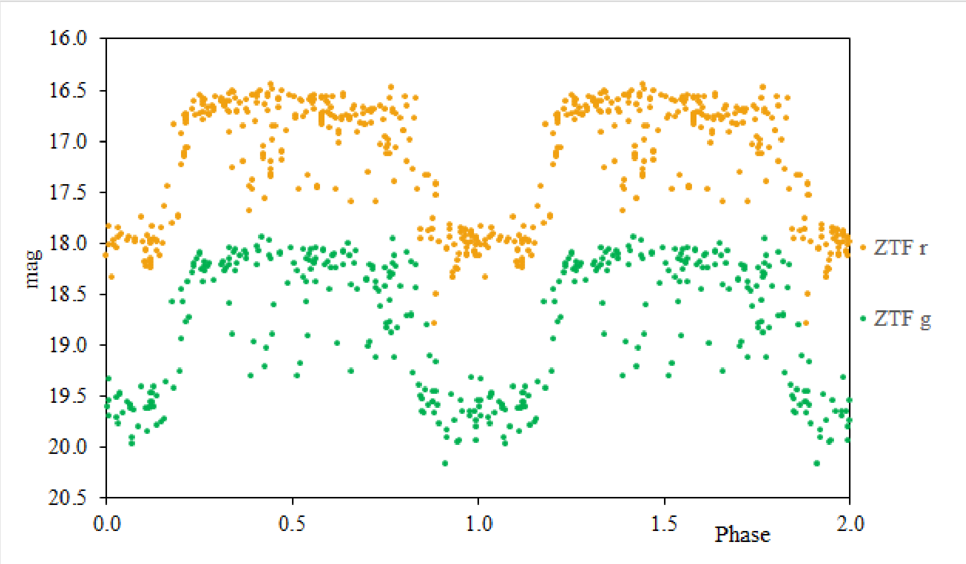

Figure 2: Phased light curve from ZTF r and g band, based on ephemeris (I), double phase view

Consistent with our prior observation in the 2022 publication, a conspicuous and comprehensive minimum recurs every 34.57 days, suggestive of KH 15D-like brightness variations. Additionally, during maximum brightness in the r and g bands, supplementary dispersion is discernible. For comparison, a phased light curve of an KH 15D candidate devoid of additional scatter in maximum light, as documented in our 2022 publication, is provided (Figure 3).

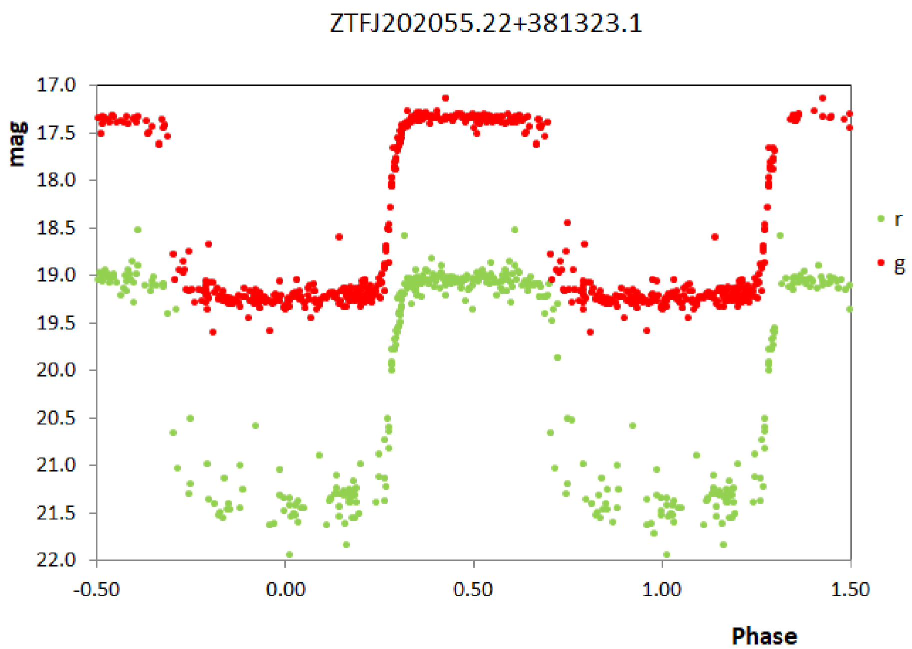

Figure 3: Phased ZTF light curve of ZTFJ202055.22+381323.1 derived from ZTF r and g bands for comparison, sourced from [7], double phase view

To validate the absence of this scatter as solely an artefact of analysis within the NASA/IPAC Infrared Science Archive, the raw images were also scrutinized utilizing MuniWin [15], affirming the photometric integrity of ZTF data retrieved from IRSA[1].

The temporal sequence of all available observations is displayed in Figure 4.

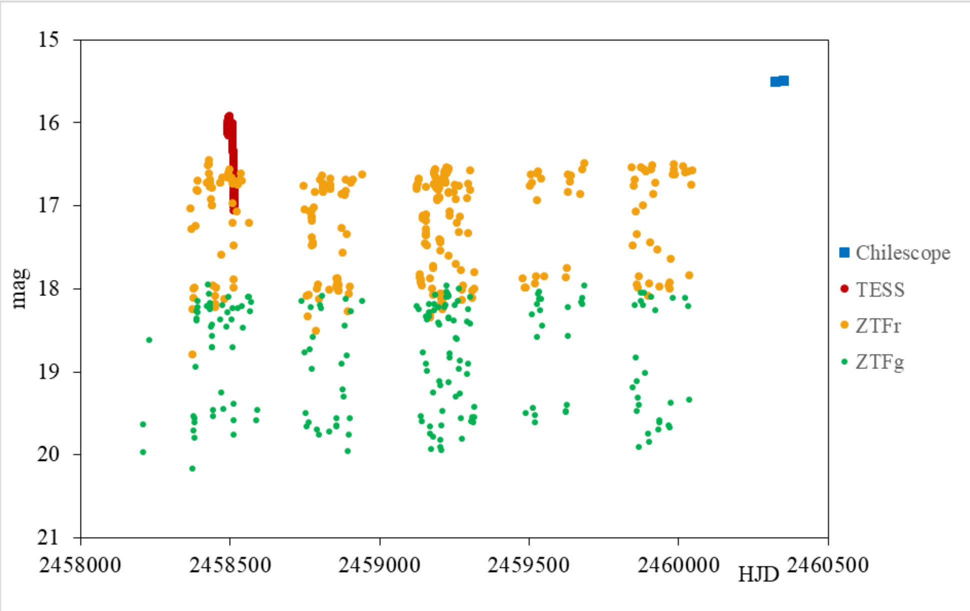

Figure 4: Light curve of ZTFJ070412.91-112403.2 including all available data

The corresponding phase-resolved light curve incorporating all observations is illustrated in Figure 5. Given the limited temporal span covered by observations from the Chilescope (Figures 6 and 7) relative to the period, Figures 4 and 5 serve to symbolically represent these observations.

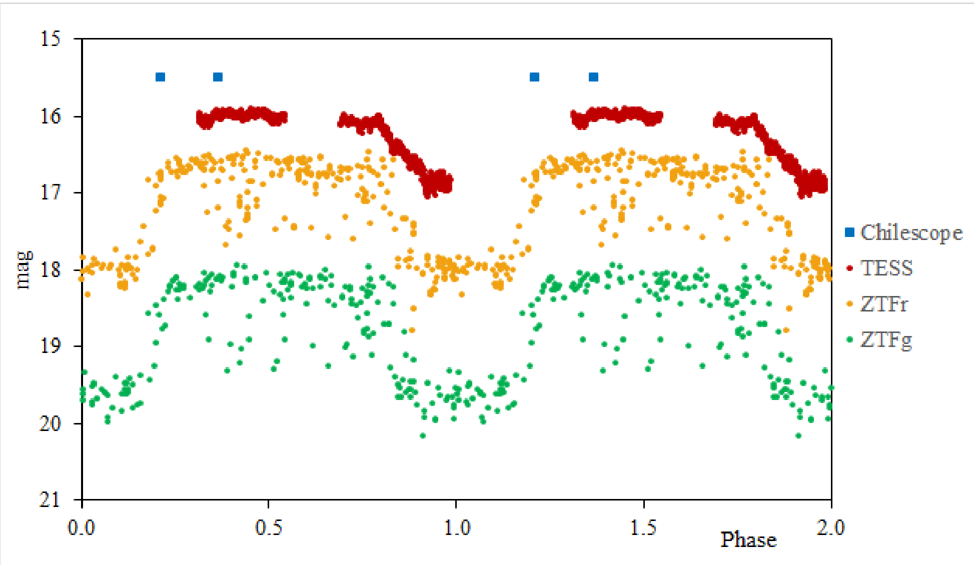

Figure 5: Phased light curve of ZTFJ070412.91-112403.2 from ZTF r and g band, based on ephemeris (I), double phase view

[1] https://irsa.ipac.caltech.edu/Missions/ztf.html

The two nights of observation utilizing the Chilescope are delineated in Figures 6 and 7, revealing possible irregular variability with an amplitude <0.1 mag within the respective observation periods.

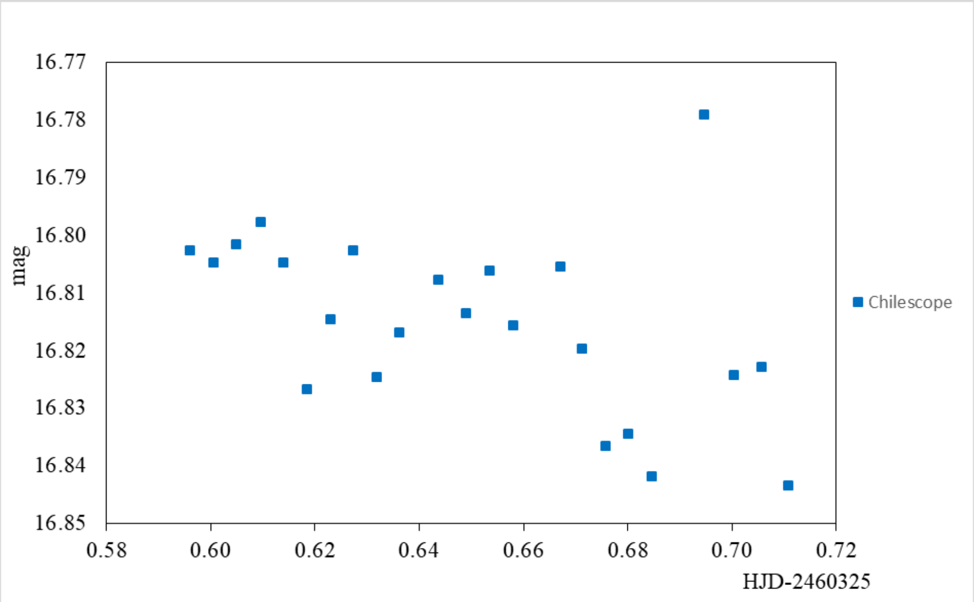

Figure 6: Wolfgang Moschner, Chilescope/El Sauce Observatory, Chile. 500 mm ASA Astrograph f/3.8 - f = 1900 mm, FLI Proline 16803 CCD-Camera - -I-U-filter.

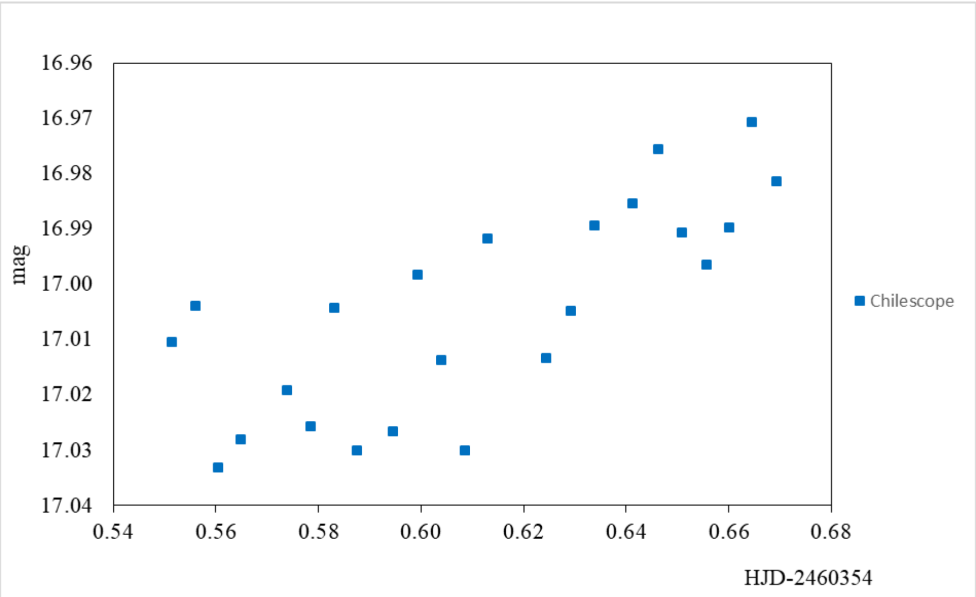

Figure 7: Wolfgang Moschner, Chilescope/El Sauce Observatory, Chile. 500 mm ASA Astrograph f/3.8 - f = 1900 mm, FLI Proline 16803 CCD-Camera - -I-U-filter.

The observation interval spanning JD 24589492 to JD 2458516, facilitating a comparative analysis between TESS observations and ZTF r and g observations, manifests notably “quiet” behavior (Figure 8).

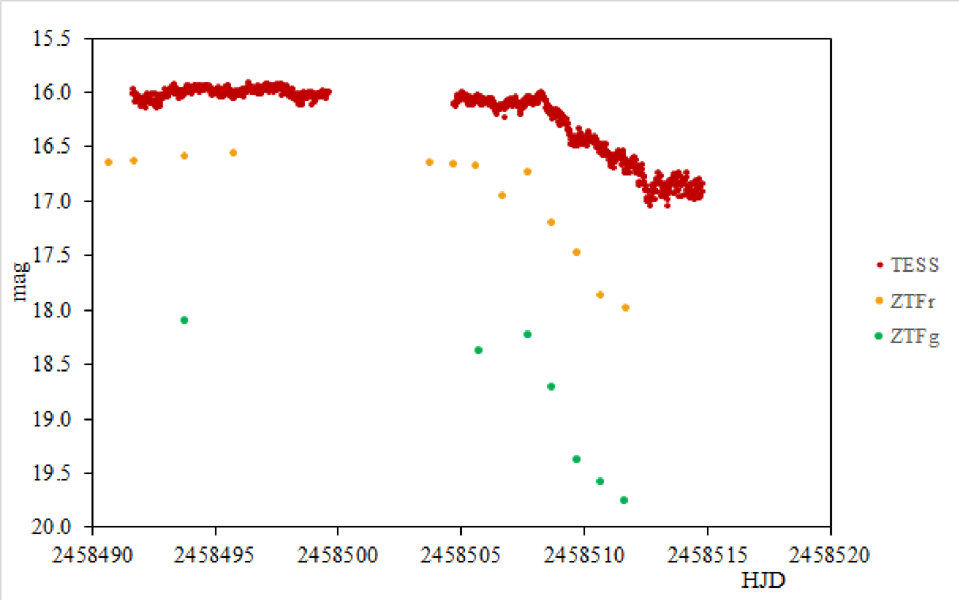

Figure 8: Light curve of ZTFJ070412.91-112403.2 (JD 2458490 – 2458520)

In contrast, ZTFJ070412.91-112403.2 exhibits heightened activity between JD 2458740 and JD 2458800. Concurrent with the minima calculated from the ephemeris (I) at JD 2458756 and JD 2458791 (indicated by blue arrows in Figure 9), additional substantial scatter in the maximum light is evident.

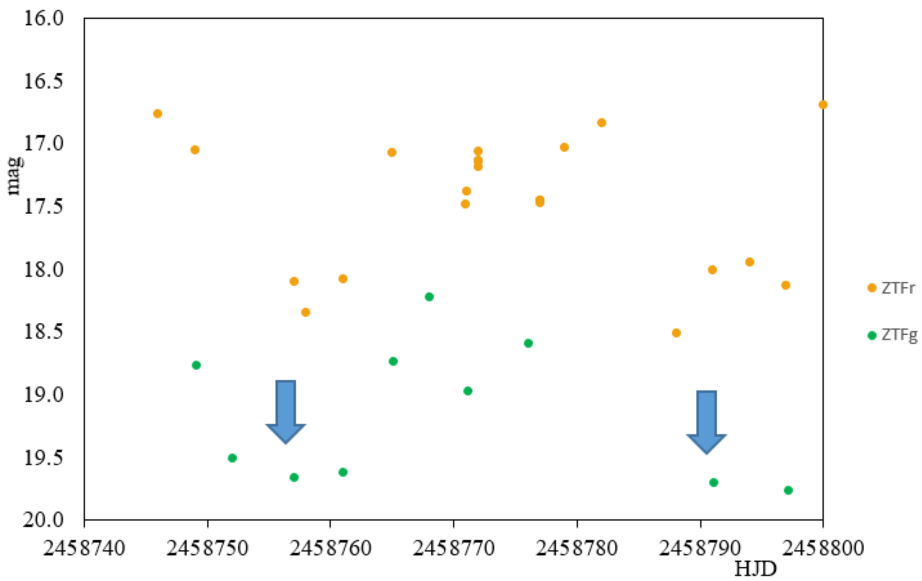

Figure 9: Light curve of ZTFJ070412.91-112403.2 (JD 2458756 - JD 2458791)

4 Conclusion

ZTFJ070412.91-112403.2 shares numerous characteristics with KH 15D analog objects, notably its probable classification as a young stellar object, along with pronounced and extensive minima persisting over years. However, in contrast to established KH 15D objects, it demonstrates irregular variability at hourly, weekly or monthly intervals. This phenomenon may arise from dust clouds along the line of sight within the nascent system. To conclusively ascertain the classification of ZTFJ070412.91-112403.2, further investigations via photometric and spectroscopic analyses are warranted.

Acknowledgements

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